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Pressure - Settlement Characteristics of Shallow Foundations using Finite Element Method

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Abstract

The present study attempts to represent the behavior of shallow foundations under the effect of eccentric inclined loading in terms of the main criteria of design which are the ultimate bearing capacity, permissible settlement, horizontal displacement and tilt. Due to the square shape of the analysed foundations, three dimensional finite element analysis are used. Elastic-perfectly plastic behavior of soil and rigid of foundations was adopted using Mohr-Coulomb criterion, 15-Node wedge elements were used to model and represent the soil and 5-Node linear elements with three degree of freedom to model and represent the foundations in used program PLAXIS 3D TUNNEL version 1.2.The results of analysis were presented in the form of pressure-settlement, pressure-horizontal displacement and pressure-tilt characteristics. Then the ultimate bearing capacity of the foundations were gotten and compared with (Meyerhof, 1956) and (Saran & Agrawal, 1991), a good agreement was found between them. Using the data obtained from the analysis, non-dimensional correlations have been developed for predicting the values of settlement, horizontal displacement and tilt of eccentrically-obliquely loaded foundations. These relationships can be used by the engineers.

Keywords: Shallow foundation, sand, eccentric-inclined load, non-dimensional correlations.

خصائص الضغط-الهطول للأسس الضحلة باستخدام طريقة العناصر المحددة

الخلاصة

قدم هذا البحث دراسة سلوك الاساس الضحل المعرض لأحمال مائلة لامركزية عن طريق ايجاد قابلية التحمل القصوى, قيمة الهبوط والازاحة الافقية والميلان المسموحة. استخدمت طريقة التحليل بالعناصر المحددة ثلاثية الابعاد لتحليل اساس مربع ضحل. فرض سلوك التربة مرن-لدن (elastic-perfectly plastic) اما الاساس ففرض بانه صلد. استخدم مور-كولومب كمحدد للفشل, استخدمت عناصر ثلاثية الابعاد ذات خمس عشرة عقدة (15-Node wedge elements) لتمثيل التربة, اما الاساس فقد استخدم عنصراً خطياً ذا خمس عقد باستخدام برنامج (PLAXIS 3D TUNNEL Version 1.2). النتائج التي استحصلت كانت بشكل خصائص ضغط-هبوط, ضغط-ازاحة افقية وضغط-ميلان وكذلك استخراج قيم قابلية التحمل ومقارنتها مع (Meyerhof, 1956) و (Saran & Agrawal, 1991). باستخدام البيانات التي تم الحصول عليها استخرجت علاقات لا بعدية للهبوط, الازاحة الافقية والميلان لأساسات معرضة لأحمال مائلة لامركزية. تستخدم هذه العلاقات في التصاميم الهندسية.

الكلمات الدالة: اساس ضحل, رمل, حمل مائل لامركزي, علاقات لابعدية.

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Introduction

Square footing is the most common type of shallow foundations that is usually used to distribute individual column loads to the surrounding soil.

In general, these foundations are subjected to vertical load, horizontal load and a moment, the resultant of these becomes eccentric inclined load on the foundation, Figure (1).

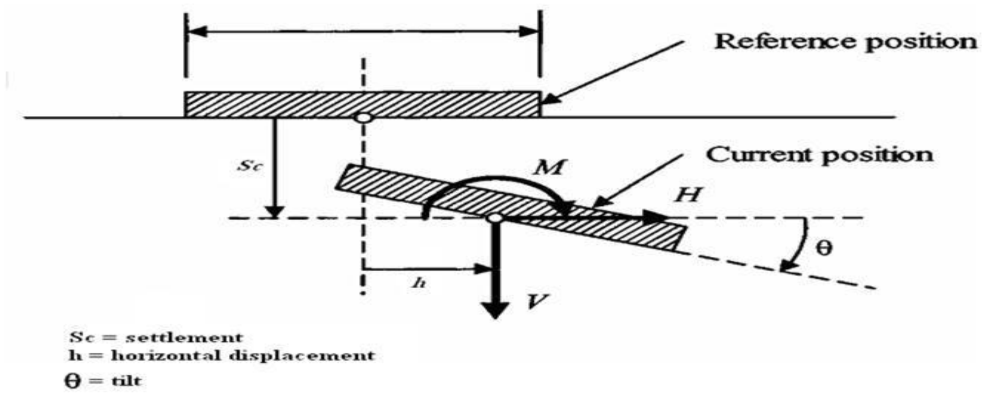

Fig. 1. Shallow Foundation Subjecte to eccentric-inclined load (after Butterfield et al. 1997)

Engineers are often required to evaluate the behavior of shallow foundations subjected to such loading and this is especially true in the problems of off-shore structures, retaining walls, columns and portal frames. Most of the published experimental data and analytical models relate to the two dimensional planar version of the problem of the shallow foundations under eccentric inclined loading conditions (Ameen, 2008)[1].

Also, there are studies about analytical three dimensional shallow foundation but it is few. Meyerhof(1953)[2] was first to study the behavior of shallow foundations under eccentric inclined loading by experimental model. The concept of reduced width for analyzing the eccentrically loaded footings was developed.

Meyerhof (1956)[3] suggested an empirical relation to compute the ultimate bearing capacity of footings subjected to eccentric-inclined loads.

Vesic (1973)[4] proposed a reduction factor to be applied in the bearing capacity equation when footing is subjected to eccentric inclined load.

Agrawal (1986)[5] performed strip, square and rectangular footings model tests on dry sand to study the behavior of footings under eccentric-inclined loads.

Nova and Montrasio (1991)[6] suggested a method to evaluate settlement and rotations of rigid shallow foundations on sand under the combined action of inclined and eccentric loads.

Ngo-Tran (1996)[7] used the FEM (finite element method) to examine the elastic behavior and stability of circular footings under combined loads using two dimensional axi-symmetric analysis.

Al-Samadi (1998)[8] studied the behavior of ring footings subjected to eccentric inclined load resting on dry sand (Dr = 70%) and he found that, for the same pressure intensity, tilt decreases with an increase in the size of footing.

Bouzid, et al (2005)[9] presented a new approximate method called the Vertical Slices Model (VSM) based on a combination of 2D finite element and finite difference methods. The method was used to predict the behavior of an embedded square footing under combined loading in a non-homogeneous half-space where the stiffness profile was modeled as a power-low of depth.

Saleh et al (2008)[10] used a laboratory work and numerical analysis to study the behavior of one sided skirted strip footing subjected to eccentric inclined load, they found that the increasing length of the skirted improve the load – settlement behavior.

Ameen (2008)[1] investigated the behavior of rectangular footing on c-φ soil and concluded equations to estimate the vertical settlement and tilt of rectangular footing subjected to eccentric inclined load.

Al-Azzawi (2010)[11] investigated the behavior of rectangular and square footing resting on gypseous soil.

Problem Definition

In this paper, an investigation of the behavior of square footings resting on dry pure sand subjected to eccentric inclined loads with many parametric study was done, Table (1). In this study, the commercial finite element program PLAXIS 3D TUNNEL version 1.2 was used.

Table 1. Parametric study

Parameters	Range of values
Depth to width ratio D_f/B	0.0 , 0.5 , 1.0
Eccentricity to width ratio e/B	0.0, 0.05, 0.1,0.15
Load inclination angle with respect to the vertical, i (degree)	0 , 4 , 8 , 12
Relative density of sand Dr (%)	84 , 46 , 9.5
Dimensions of footing (mm)	500*500*300 750*750*450 1000*1000*600

Materials and Methods

Model development

In this study, the soil was modeled using three dimensional element with 5-Node wedge and six stress points (stress or Gauss point), Figure (2).

The footing was modeled using linear element with five nodes with three degree of freedom (u, v, ϑ).

Figure (3) shows a finite element mesh that used capacity of footing in this study. The lateral and bottom boundaries of the finite element meshed were change according to the width of footing (Bowels, 1988)[12].
The dimensional in the x-direction = B + 4B*2
The dimensional in the y-direction = B + 4B*2
The dimensional in the z-direction = 6B
Where B is the footing width.

The footing was considered to be rigid and rough, as it most often is in reality and was modeled as elastic with much greater stiffness than the soil (footing stiffness (E) = $26*10^6$ kN/m^2, unit weight of concrete (γ) = 24 kN/m^3, Poisson's ratio of concrete (μ) = 0.2)(Bowles, 1996)[13]. The soil was modeled with Mohr coulomb yield criterion and assumed that the soil is elastic perfectly plastic material, it's properties recorded in Table (2).

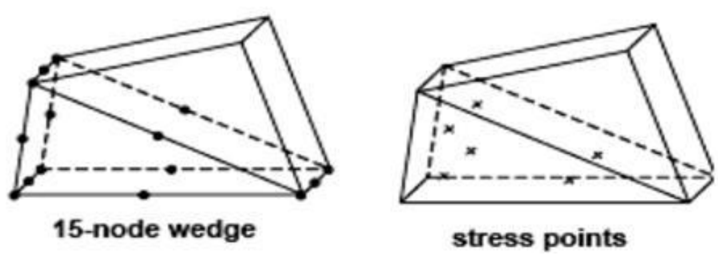

Fig. 2. Three dimensional element with 15-Node wedge and 6 stress points

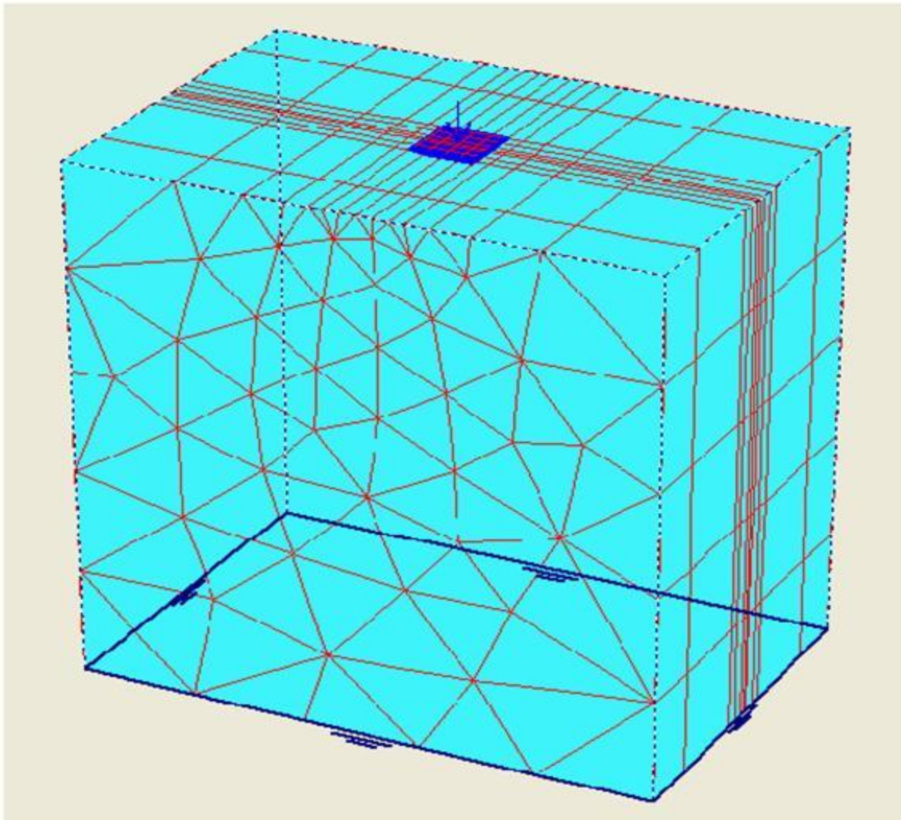

Fig. 3. Finite element mesh (not to scale)

Table 2. Properties of the used soil(from Agrawal,1986)

Soil properties \ Soil type	Loose Sand	Medium Sand	Dense Sand
Modulus of elasticit , E kN/m^2	37500	27500	23500
Unit weight, γ kN/m^3	16.3	15.2	14.3
Poisson's ratio, μ	0.26	0.29	0.34
Internal friction, φ degree	41	36	29.5
Cohesion, c kN/m^2	0.01	0.01	0.01
Angle of dilatancy, ψ degree	11	6	0.0
Interface reduction factor, $R_{intr.}$	1.0	1.0	1.0

Model Verification

A comparison was made between the used program and an earlier study (Agrawal, 1986)[5]. The comparison gave a good agreement. Figure (4) shows some curves.

Results and Discussion

Curves were drawn between the settlement (Se), horizontal displacement (δh) and tilt (t) with the applied pressure. From pressure-settlement curves, bearing capacity values were found (the bearing capacity was found by De Beer method at D_f = 0 and by Tangent method at D_f = 0.5,1.0, Figures (4) and (5), and compared with (Meyerhof 1956[3], Saran & Agrawal 1991[14]). Table (3) shows the bearing capacity of footing in this study, and Figures (7) shows the comparison of bearing capacity with another studies.

Also, values of settlement (maximum settlement, Sm and settlement at point load, Se) and horizontal displacement were found, Table (4). These values were divided by So (So is a vertical settlement under central vertical load) to get a non-dimensional values, Table (5).

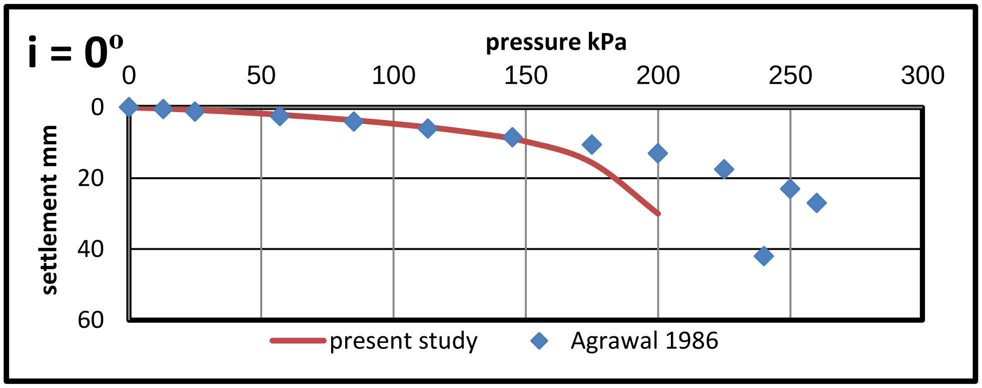

Fig. 4a. Comparison of settlement between Present study and Agrawal 1986 for (e/B = 0 and i=0°)

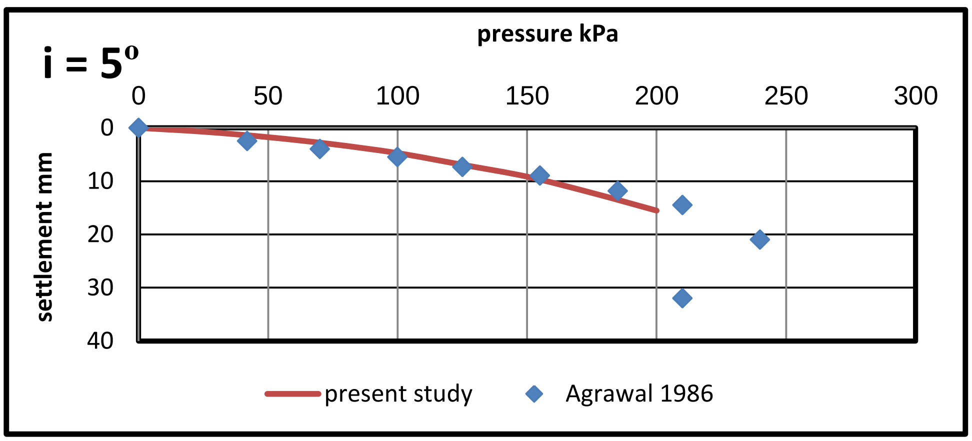

Fig. 4b. Comparison of settlement between Present study and Agrawal 1986 for (e/B = 0 and i=5°)

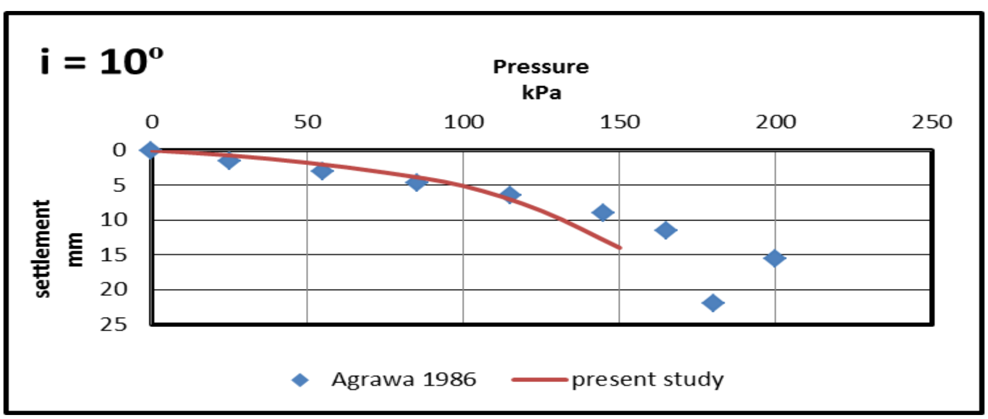

Fig. 4c. Comparison of settlement between Present study and Agrawal 1986 for (e/B = 0 and i=10°)

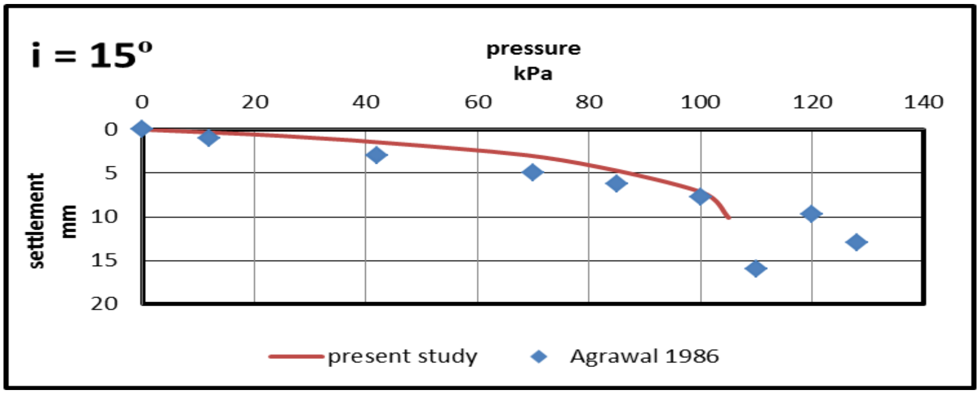

Fig. 4d. Comparison of settlement between Present study and Agrawal 1986 for (e/B = 0 and i=15°)

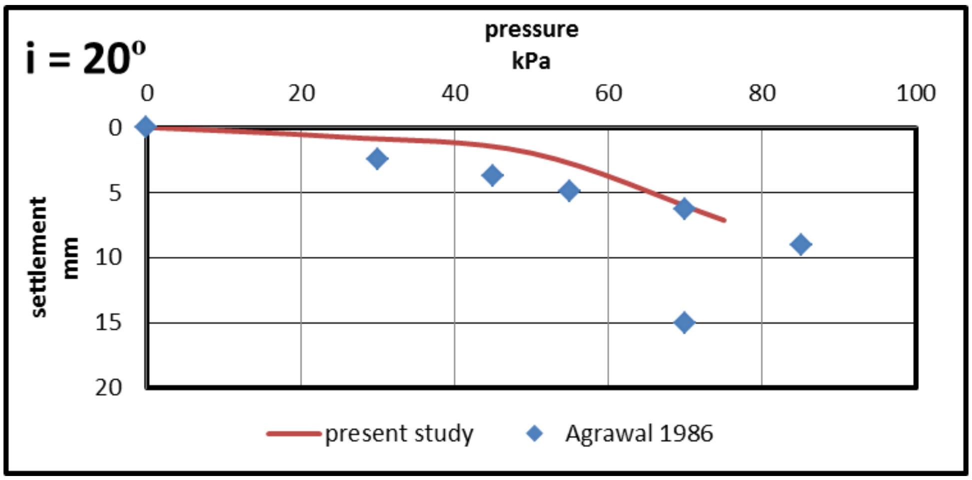

Fig. 4e. Comparison of settlement between Present study and Agrawal 1986 for (e/B = 0 and i=20°)

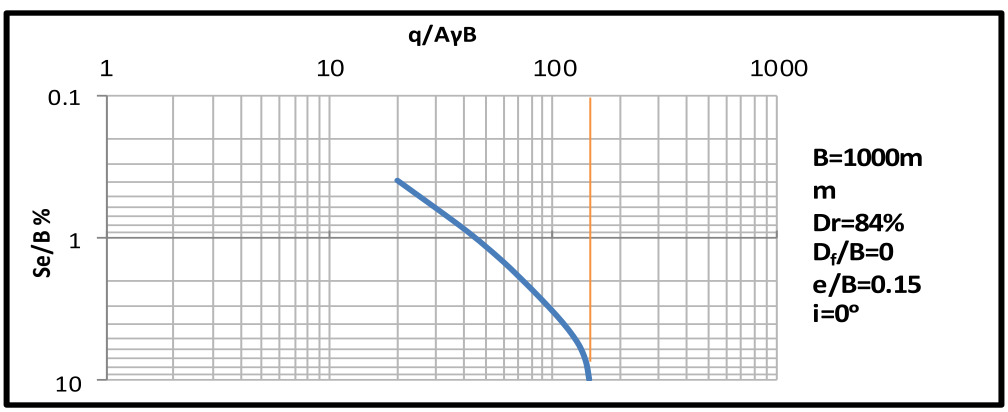

Fig. 5. Non dimensional pressure-settlement curve of square footing on dense sand (De Beer, 1970)

Table 3. Comparison of bearing capacity on dense sand

			Ultimate Bearing Capacity (kPa)								
			Df/B = 0			Df/B = 0.5			Df/B = 1		
			B (mm)			B (mm)			B (mm)		
No.	e/B	i°	500	750	1000	500	750	1000	500	750	1000
1	2	3	4	5	6	7	8	9	10	11	12
1	0	0	769.9	1053	1369	1580	1860	2420	2300	2920	3200
2		4	635.7	855.7	1232	1270	1550	2270	2000	2600	3000
3		8	542.7	676.8	1136	1050	1495	1980	1740	2300	2900
4		12	458	504.2	723.7	985	1280	1700	1590	2000	2600
5	0.05	0	719.9	927.2	1247	1300	1680	2190	2040	2700	2900
6		4	586.8	836.8	1167	1030	1470	1840	1900	2320	2850
7		8	488	684.6	917	955	1400	1650	1660	2090	2720
8		12	360	494.3	665.4	922	1230	1590	1520	1910	2550
9	0.1	0	552.8	842.8	1142	1280	1630	2100	1800	2420	2850
10		4	487.7	697.7	924.2	1000	1370	1800	1650	2200	2820
11		8	404.9	561	723.7	865	1300	1590	1450	2010	2600
12		12	327.6	426.7	586.8	855	1140	1480	1380	1850	2300
13	0.15	0	517.7	780	1066	1040	1520	1990	1600	2400	2820
14		4	480	701.1	911	900	1300	1780	1550	2150	2800
15		8	401	515	686.7	850	1100	1540	1380	1920	2400
16		12	315.8	420.7	562.2	805	980	1370	1240	1800	2090

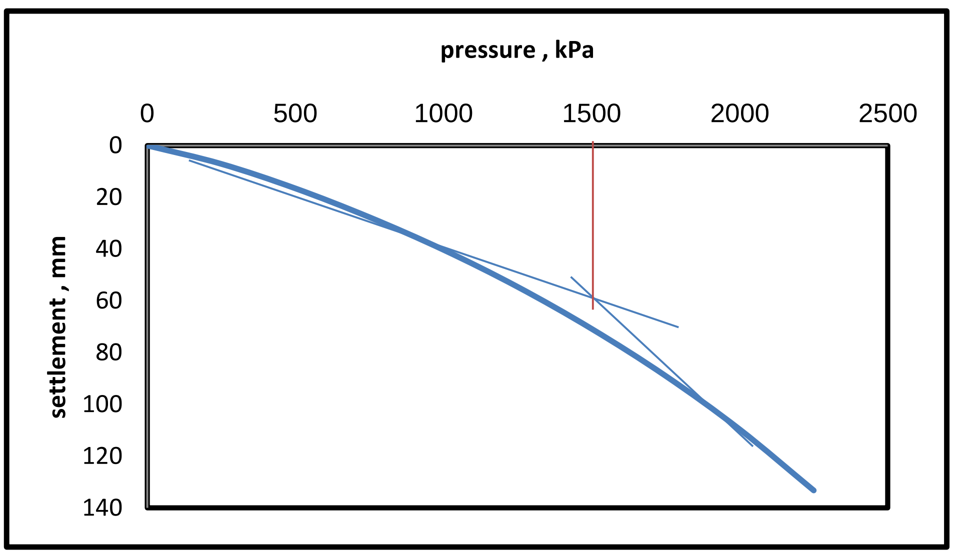

Fig. 6. Tangent method to find the value of bearing capacity of square footing on dense sand (D_f = 0.5, B = 1000, e/B = 0.1, i = 8^{o})

Table 4. Se , Sm and δh for square footing on dense sand (B = 1000mm)

				Factor of safety = 1			Facter of safety = 2			Factor of safety = 3		
No.	Df/B	e/B	i°	Se (mm)	Sm (mm)	δh (mm)	Se (mm)	Sm (mm)	δh (mm)	Se (mm)	Sm (mm)	δh (mm)
1	2	3	4	5	6	7	8	9	10	11	12	13
1	0	0	0	120	120	0	36	36	0	21	21	0
2			4	104	104	38	30	30	4	16	16	2
3			8	94	94	56	27.5	27.5	8.5	15	15	4
4			12	45.5	45.5	28	15	15	6	8.5	8.5	2.5
5		0.05	0	100	118.8	0	30	34.71	0	17	19.36	0
6			4	92	119.1	42.5	27.5	31.82	6.5	16	18.36	3
7			8	74	96.77	46	21	24.93	7.5	12	13.57	4
8			12	42	53	27.5	14	16.36	6	8.5	9.521	3.25
9		0.1	0	84	114.7	0	28	35.12	0	16	18.44	0
10			4	80	111.4	45	23	28.59	7.5	13	15.79	3.5
11			8	74	106.1	54	16.5	21.04	6.5	9.5	11.94	3.25
12			12	47.5	67.74	44	12.5	15.99	6	7.5	9.245	3
13		0.15	0	68	110.7	0	28	35.33	0	16	19.67	0
14			4	65	104.1	52	24	32.55	9.5	14	18.28	4.25
15			8	64	93.9	50	17.5	23.61	8	10	13.05	4
16			12	42.5	61.73	38.5	13.8	18.38	7.5	8	10.44	3.5
17	0.5	0	0	123	123	0	48	48	0	29	29	0
18			4	110	110	19	42	42	4	25	25	2
19			8	92	92	21	36	36	8	22	22	4
20			12	76	76	30	30	30	10	18	18	6
21		0.05	0	108	122.1	0	40	44.71	0	24	26.75	0
22			4	85	97.57	15	32	37.11	5	20	22.36	2
23			8	74	86.17	24	28.5	32.43	7.5	17	19.36	4
24			12	72	85.35	35.5	27	31.56	11	16	18.36	5
25		0.1	0	100	119.5	0	40	45.59	0	24	28.19	0
26			4	89	114.8	39	35	43.38	8	20	24.89	4
27			8	77	100.7	35	29	36.68	10	17	21.19	4.5
28			12	72	95.03	42	26.5	33.48	12	16	20.05	6
29		0.15	0	88	119.7	0	38	45.21	0	23	28.19	0
30			4	88	116.1	28	36	44.55	9	21	25.89	5
31			8	76	99.2	33	29	36.94	10.5	18	22.89	8
32			12	66	86.64	38	25	32.21	12	15.5	19.78	6
33	1	0	0	135	135	0	60	60	0	34	34	0
34			4	126	126	14	52	52	7.8	32	32	3.5
35			8	120	120	26	50	50	10	30	30	6
36			12	105	105	32.5	43	43	12	27	27	8
37		0.05	0	122	135	0	51	56.5	0	30	33.14	0
38			4	121	133.6	16.5	50	54.71	8	29	32.14	4
39			8	117	129.4	28	47	51.71	10.5	28	30.98	6
40			12	107	118	36	40	43.93	13	25	27.75	8
41		0.1	0	113	133.9	0	50	58.38	0	28	33.59	0
42			4	102	124.3	24	45	53.38	8	27	32.45	4.5
43			8	97	116.5	33	38	46.03	12	24	28.54	7.5
44			12	93	109.8	38	37	43.28	15	22	25.84	8
45		0.15	0	105	134.3	0	44	56.22	0	28	32.89	0
46			4	96.5	127	32	40	52.22	12	27	31.89	6
47			8	90.8	115.2	36	36	45.77	13	24.5	30.61	8
48			12	83	102.5	39	34	41.33	14	21	25.89	9

Table 5. Se/So , Sm/So and δh/B for square footing on dense sand (B=1000mm)

No.	Df/B	e/B	i°	Factor of safety = 1			Facter of safety = 2			Factor of safety = 3		
				Se/So	Sm/So	δh/B	Se/So	Sm/So	δh/B	Se/So	Sm/So	δh/B
1	2	3	4	5	6	7	8	9	10	11	12	13
1	0	0	0	1	1	0	1	1	0	1	1	0
2			4	0.867	0.867	0.038	0.833	0.833	0.004	0.762	0.762	0.002
3			8	0.783	0.783	0.056	0.764	0.764	0.009	0.714	0.714	0.004
4			12	0.379	0.379	0.028	0.417	0.417	0.006	0.405	0.405	0.003
5		0.05	0	0.833	0.99	0	0.833	0.964	0	0.81	0.922	0
6			4	0.767	0.992	0.043	0.764	0.884	0.007	0.762	0.874	0.003
7			8	0.617	0.806	0.046	0.583	0.692	0.008	0.571	0.646	0.004
8			12	0.35	0.442	0.028	0.389	0.454	0.006	0.405	0.453	0.003
9		0.1	0	0.7	0.956	0	0.778	0.976	0	0.762	0.878	0
10			4	0.667	0.928	0.045	0.639	0.794	0.008	0.619	0.752	0.004
11			8	0.617	0.884	0.054	0.458	0.584	0.007	0.452	0.569	0.003
12			12	0.396	0.564	0.044	0.347	0.444	0.006	0.357	0.44	0.003
13		0.15	0	0.567	0.922	0	0.778	0.981	0	0.762	0.936	0
14			4	0.542	0.868	0.052	0.667	0.904	0.01	0.667	0.87	0.004
15			8	0.533	0.782	0.05	0.486	0.656	0.008	0.476	0.622	0.004
16			12	0.354	0.514	0.039	0.383	0.511	0.008	0.381	0.497	0.004
17	0.5	0	0	1	1	0	1	1	0	1	1	0
18			4	0.894	0.894	0.019	0.875	0.875	0.004	0.862	0.862	0.002
19			8	0.748	0.748	0.021	0.75	0.75	0.008	0.759	0.759	0.004
20			12	0.618	0.618	0.03	0.625	0.625	0.01	0.621	0.621	0.006
21		0.05	0	0.878	0.993	0	0.833	0.932	0	0.828	0.922	0
22			4	0.691	0.793	0.015	0.667	0.773	0.005	0.69	0.771	0.002
23			8	0.602	0.701	0.024	0.594	0.676	0.008	0.586	0.667	0.004
24			12	0.585	0.694	0.036	0.563	0.657	0.011	0.552	0.633	0.005
25		0.1	0	0.813	0.972	0	0.833	0.95	0	0.828	0.972	0
26			4	0.724	0.933	0.039	0.729	0.904	0.008	0.69	0.858	0.004
27			8	0.626	0.819	0.035	0.604	0.764	0.01	0.586	0.731	0.005
28			12	0.585	0.773	0.042	0.552	0.698	0.012	0.552	0.691	0.006
29		0.15	0	0.715	0.973	0	0.792	0.942	0	0.793	0.972	0
30			4	0.715	0.944	0.028	0.75	0.928	0.009	0.724	0.893	0.005
31			8	0.618	0.807	0.033	0.604	0.77	0.011	0.621	0.789	0.008
32			12	0.537	0.704	0.038	0.521	0.671	0.012	0.534	0.682	0.006
33	1	0	0	1	1	0	1	1	0	1	1	0
34			4	0.933	0.933	0.014	0.867	0.867	0.008	0.941	0.941	0.004
35			8	0.889	0.889	0.026	0.833	0.833	0.01	0.882	0.882	0.006
36			12	0.778	0.778	0.033	0.717	0.717	0.012	0.794	0.794	0.008
37		0.05	0	0.904	1	0	0.85	0.942	0	0.882	0.975	0
38			4	0.896	0.989	0.017	0.833	0.912	0.008	0.853	0.945	0.004
39			8	0.867	0.959	0.028	0.783	0.862	0.011	0.824	0.911	0.006
40			12	0.793	0.874	0.036	0.667	0.732	0.013	0.735	0.816	0.008
41		0.1	0	0.837	0.992	0	0.833	0.973	0	0.824	0.988	0
42			4	0.756	0.921	0.024	0.75	0.89	0.008	0.794	0.954	0.005
43			8	0.719	0.863	0.033	0.633	0.767	0.012	0.706	0.839	0.008
44			12	0.689	0.813	0.038	0.617	0.721	0.015	0.647	0.76	0.008
45		0.15	0	0.778	0.995	0	0.733	0.937	0	0.824	0.967	0
46			4	0.715	0.941	0.032	0.667	0.87	0.012	0.794	0.938	0.006
47			8	0.673	0.853	0.036	0.6	0.763	0.013	0.721	0.9	0.008
48			12	0.615	0.76	0.039	0.567	0.689	0.014	0.618	0.761	0.009

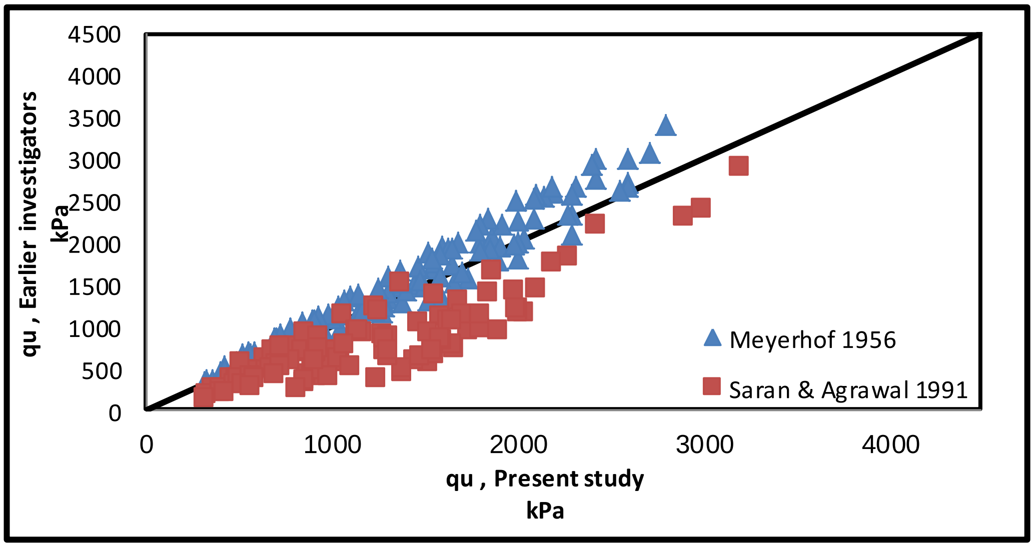

Fig. 7. Comparison of bearing capacity on dense sand

Non – Dimensional Correlations-Settlement (Se)

For dense sand

$$\frac{S_e}{S_o} = (-0.047i^3 + 0.947i^2 - 4.742i + 23.86)$$
$$(\frac{e}{B})^2 + (0.012i^3 - 0.237i^2 + 1.07i - 5.116)(\frac{e}{B})$$
$$- 0.021i + 0.979 \quad \ldots\ldots(1)$$

For medium dense sand

$$\frac{S_e}{S_o} = (-0.1645i^3 + 3.1543i^2 - 14.745i + 30.02)(\frac{e}{B})^2$$
$$+ (0.0209i^3 - 0.4186i^2 + 2.1059i - 5.949)(\frac{e}{B})$$
$$- 0.03i + 0.9817 \quad \ldots\ldots(2)$$

For loose sand

$$\frac{S_e}{S_o} = (0.0393i^3 - 0.8396i^2 + 4.6414i + 23.46)(\frac{e}{B})^2$$
$$+ (0.0021i^3 - 0.0228i^2 + 0.0181i - 5.285)(\frac{e}{B})$$
$$- 0.0276i + 0.9956 \quad \ldots\ldots(3)$$

Maximum Settlement (Sm)

For dense sand

$$\frac{S_m}{S_o} = (0.0315i^3 - 0.5851i^2 + 5.9934i + 14.269)(\frac{e}{B})^2$$
$$+ (-0.0014i^3 + 0.029i^2 - 0.5996i - 2.37)(\frac{e}{B})$$
$$- 0.0284i + 1.0036 \quad \ldots\ldots(4)$$

For medium dense sand

$$\frac{S_m}{S_o} = (-0.0543i^3 + 0.899i^2 - 1.999i + 40.309)(\frac{e}{B})^2$$
$$+ (0.0106i^3 - 0.1779i^2 + 0.5711i - 6.1939)(\frac{e}{B})$$
$$- 0.0318i + 1.0183 \quad \ldots\ldots(5)$$

For loose sand

$$\frac{S_m}{S_o} = (-0.1936i^3 + 3.4064i^2 - 11.808i + 44.793)(\frac{e}{B})^2$$
$$+ (0.0282i^3 - 0.5142i^2 + 2.0136i - 6.8931)(\frac{e}{B})$$
$$- 0.0289i + 0.9958 \quad \ldots\ldots(6)$$

Horizontal Displacement (δ_h)

<u>For all types of sand</u>

$$\frac{\delta_h}{B} = (0.5079 i^2 - 10.581 i + 55.459)(\frac{i}{\phi})^2$$
$$+ (-0.1028 i^2 + 2.1848 i - 12.82)(\frac{i}{\phi})$$
$$-0.0026 i^2 + 0.0574 i - 0.0165 \ldots\ldots\ldots\ldots\ldots\ldots(7)$$

Where:
S_o: vertical settlement under central vertical load.
S_e: settlement at point load.
S_m: maximum settlement.
δ_h: horizontal displacement.
e: eccentricity.
B: footing width.
i: load inclination.
ϕ: friction angle.

Influence of the Footing's Width

A non-dimensional relations were drawn between q/γB and Se/B to study the influence of width of the footing (B), Figure (8). It was found that increasing the width caused increasing the settlement under the same pressure.

Pressure Settlement Relationship

From pressure – settlement curves, it was noticed that increasing the applied load's inclination caused increasing in settlement and decreasing in bearing capacity. This happened because of increasing the horizontal force component.

Also, it was found that increasing the ratio of footing embedment to width (D_f/B) caused decreasing in settlement and increasing in bearing capacity obviously, because of the over burden pressure helped to increasing the bearing capacity of the soil.

Pressure Horizontal Displacement Relationship

From pressure – horizontal displacement curves were noticed that increasing the load's inclination caused increasing in horizontal displacement. While increasing in eccentricity to width ratio or footing embedment to width ratio caused decreasing in horizontal displacement.

Pressure Tilt Relationship

The value of tilt was calculated from the equation below:(Saran and Niyogi, 1970)[15]

$$\sin t = \frac{S_m - S_e}{\frac{B}{2} - e} \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots(8)$$

where :
S_m: maximum settlement of footing at the pressure applied.
S_e: settlement of footing at the point of applied pressure.
B: width of footing.
e: eccentricity.
t: tilt of footing.

From which curves were noticed that the tilt of footing increase by increasing the load inclination (i) and the eccentricity to width ratio (e/B), and decrease by increasing the footing embedment to width ratio (D_f/B).

0.098 57.76687

q/Bγ	se/B	q/Bγ	se/B	q/Bγ
0	0	0	0	0
6.134969	0.002417	5.816769	0.000794	2.944785
12.26994	0.005201	11.63354	0.00164	5.889571
18.40491	0.008777	17.45031	0.002638	8.834356

Fig. 8a. Influence of B at e/B = 0 and i=0º

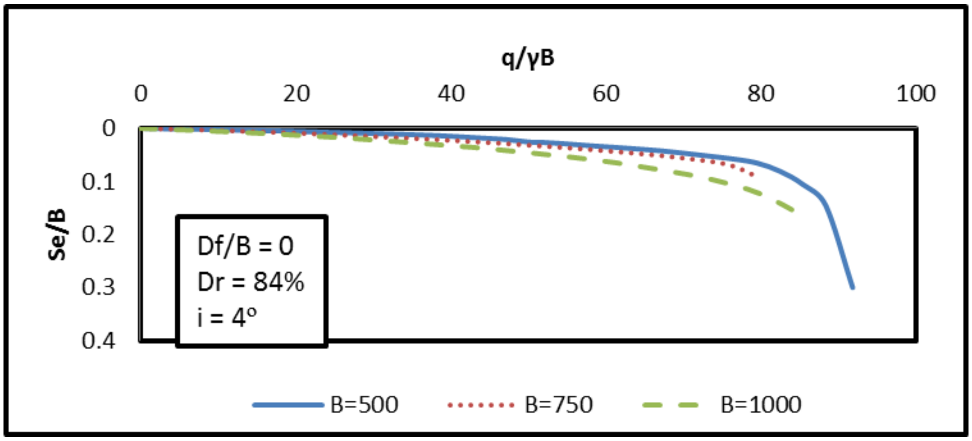

Fig. 8b. Influence of B at e/B = 0 and i=4º

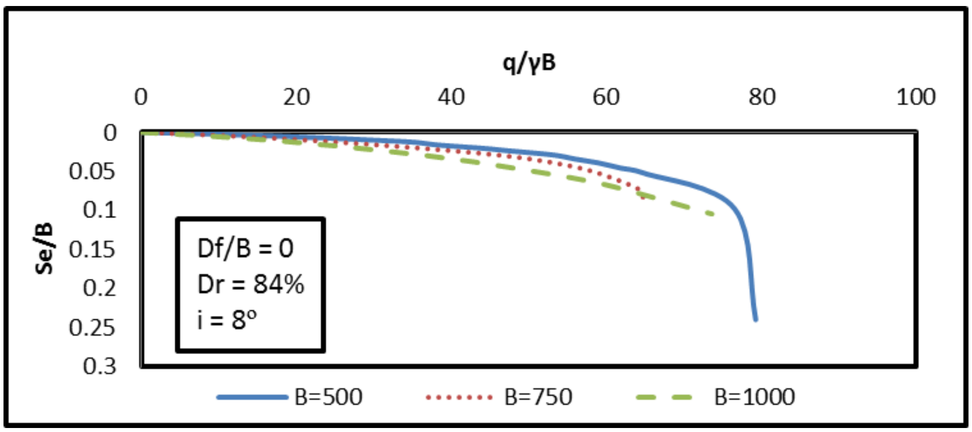

Fig. 8c. Influence of B at e/B = 0 and i=8º

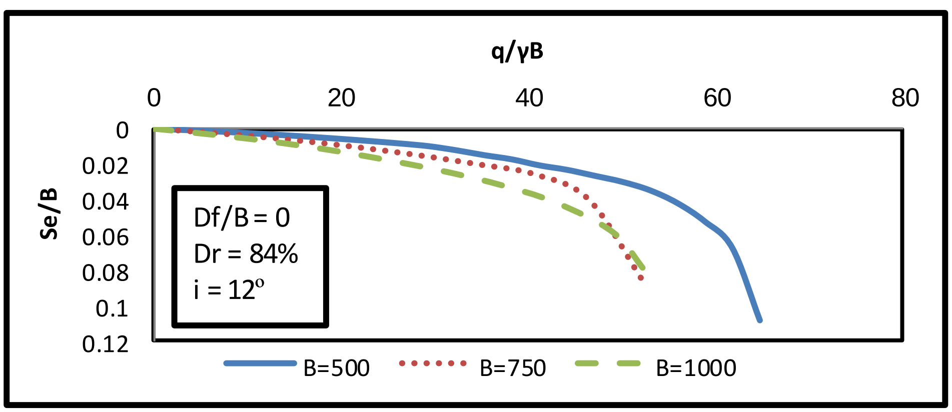

Fig. 8c. Influence of B at e/B = 0 and i=12º

Conclusions

1- Analysis the square shallow foundation at different depth under vertical, inclined, eccentric, inclined-eccentric loads using PLAXIS 3D TUNNEL program gave a good agreement when compared with previous studies.

2- The ultimate bearing capacity decreases when the load inclination and eccentricity increase, the settlement of footing increases when the load inclination and eccentricity increase, the horizontal displacement increases when the load inclination increase while it decreases when the eccentricity increase. Using the embedment footing improve the bearing capacity of soil.

3- A non-dimensional correlations were gotten and can be used in engineering design. This correlation to predict the settlement, tilt and horizontal displacement

4- The correlations to predict the tilt and settlement are dependent upon eccentricity-width ratio, density of soil and inclination of load, and they are independent upon factor of safety, depth-width ratio, and width of footing.

5- The correlation to predict the horizontal displacement is dependent upon density of soil and inclination of load, and it is independent upon factor of safety, eccentricity-width ratio, and depth-width ratio.

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